# ARTICLE COMPRISING A MULTI-CHANNEL DISPENSING HEAD

## Statement of Related Applications

This application claims priority of Provisional Application 60/153,879 filed September 14, 1999.

## Field of the Invention

The present invention relates to liquid dispensers. More particularly, the present invention relates to a multi-channel liquid dispenser capable of dispensing very small volumes of fluid.

## Background of the Invention

Pharmaceutical, combinatorial chemistry, high-throughput screening, and medical diagnostics applications, among others, require dispensing very small volumes of liquid (*i.e.*, nano-liters to micro-liters) into a receiver such as a micro-titer plate. It is usually necessary to perform the dispensing operation without cross-contamination, which might occur, for example, if a reagent is being added to a receiver that already contains another reagent.

To substantially eliminate the incidence of cross-contamination, a "non-touch off" method of liquid dispensing is typically used. In this method, a droplet being dispensed does not contact the receiver (or liquid or other material in the receiver) until the droplet completely disengages from the tip of the dispenser. Non-touch-off dispensing requires supplying enough kinetic energy to a liquid droplet for it to overcome the surface tension of the dispensing tip and enough kinetic energy so that it can be accurately and reliably directed to a desired destination.

Non-touch off dispensing of liquid volumes between about 0.1 to about 5 micro-liters is performed using either shake-off methods or implemented with various valve mechanisms that apportion the dispensed volume. While the use of valves for this service is straightforward in principle, it is rather difficult to implement in practice.

One valve-based prior art technique dispensing technique is the "positive displacement" method. In this method, liquid is pressurized into a valve, typically using a syringe or pump, while a synchronized valve controller opens and closes the valve to expel the liquid. This technique has several drawbacks.

First, the accuracy of the dispensing operation is highly dependent upon the precise coordination of all controls, and is a strong function of the elasticity of the liquid channel and temperature. Moreover, accuracy is affected by the presence of trapped or internally released gas bubbles.

Second, this technique suffers from an unavoidable drop in liquid pressure during each dispensing cycle. As a consequence of the pressure drop, only a portion of the liquid that is advanced to the valve for dispensing each cycle is actually dispensed. This drop in pressure is caused by the delay between pump/syringe action and high-speed valve operation. While certain feedback and sensory elements can improve or at least monitor the operation, the design and implementation of the system becomes quite complicated.

There are some additional drawbacks that affect most prior art liquid dispensers regardless of operating principles.

For instance, in most prior art liquid dispensers, liquid travels a relatively large distance through tubing, *etc.*, to reach the dispensing valve. This long travel distance might result in changes in liquid volume due to temperature/viscosity fluctuations, internal gas bubbles, elasticity variations of the tubing, and the like. Moreover, long tubing runs generally result in reagent losses during priming, cleaning and servicing operations.

Furthermore, most prior art liquid dispensers (especially multi-head liquid dispensers) are expensive. The expense is related to, among other elements, relatively complex positioning devices that position the dispensing heads.

There is a need, therefore, for a liquid dispenser that is capable of high-speed liquid delivery and is simpler, more reliable and less expensive than existing dispensers.

## Summary of the Invention

In accordance with some embodiments of the present invention, a multi-channel fluid dispenser that avoids some of the problems of the prior art is disclosed.

In the illustrative embodiment, a multi-channel fluid dispenser includes a reservoir, a multi-channel liquid dispensing head, a plurality of fluid-delivery conduits, and support and positioning elements.

The reservoir advantageously has multiple internal chambers for segregating liquid within the reservoir, as well as a non-compartmentalized region that overlies the chambers. The non-compartmentalized region facilitates an even distribution of pressure within the reservoir, thereby promoting the balanced dispensing of liquids from the various chambers.

The fluid-delivery conduits receive liquid from the chambers in the reservoir and deliver it to the dispensing head. The support and positioning elements are operable to support and position the dispensing head so that it can deliver the liquid from the reservoir to an underlying receiver.

In some embodiments of the invention, the multi-channel liquid dispensing head includes a valve-support member, a plurality of valves and a plurality of nozzles. The multi-channel liquid dispensing head is supported by a positioning member that engages the valve support plate.

The multi-channel liquid dispensing head is advantageously movable along three-axis to facilitate alignment with an underlying receiver. In one embodiment of the invention, elongate holes in the positioning member and elongate holes in the valve-support member cooperate to provide two-axis positioning. A separate positioning mechanism provides movement along the third axis.

In one embodiment of the present invention, the valves are attached the valve-support member by a fastener, such as a nut. The valves are received by an eccentrically-disposed hole in the fastener. Due to the eccentrically-disposed hole, as the fastener is rotated, the valves tilt relative to the vertical and the liquid dispensed from such tilted valves is directed at a non-normal angle into a receiver.

In further embodiments, the fluid-delivery conduits include one or more optional flow control features that improve the accuracy of the dispensing operation. These and other features of the present invention are described in further detail in the Detailed Description with reference to the attached drawing Figures.

## Brief Description of the Drawings

**FIG. 1** depicts a front-view of a multi-channel dispenser in accordance with the illustrative embodiment of the present invention.

**FIG. 2** depicts a cross-sectional side view of the dispenser shown in FIG. 1.

**FIG. 3** depicts a u-shaped support member that supports a multi-channel liquid dispensing head.

**FIG. 4** depicts a horizontally-disposed positioning member that engages the u-shaped suppport member of FIG. 3.

**FIG. 5** depicts a valve-support member that receives the dispensing valves.

**FIG. 6** depicts a cross-sectional side view of the valve-support member of FIG. 5.

**FIG. 7** depicts a plan view of the valve-support member of FIG. 5.

**FIG. 8** depicts a multi-channel liquid dispensing head including the valve-support member of FIG. 5, and a plurality of valves and integrated nozzles.

**FIGS. 9A – 9C** depict a receiver that is tilted with respect to the head of FIG. 8.

**FIG. 10** depicts an illustrative embodiment of multi-channel dispenser/aspirator in accordance with the present invention having a compartmentalized reservoir.

**FIG. 11** depicts a further embodiment wherein the multi-channel dispenser includes an incremental positioner for advancing a receiver towards the dispensing valves.

**FIG. 12** depicts a nut with an eccentrically-disposed hole.

**FIG. 13** depicts a nozzle tilted relative to the vertical by adjusting the nut of FIG. 12.

**FIG. 14** depicts various optional flow control/flow regulation features for use with fluid-delivery conduits.

## Detailed Description

FIG. 1 (front view) and FIG. 2 (side view) depict multi-channel dispenser **100** in accordance with the illustrative embodiment of the present invention. Dispenser **100** comprises support member **102**, horizontally-disposed positioning member **104**, reservoir **106**, a plurality of fluid-delivery conduits **108** and multi-channel liquid dispensing head **110**, interrelated as shown. Multi-channel liquid dispensing head **110** comprises valve-support member **526**, and a plurality of valves **838** with integrated nozzles **840**.

Liquid that is stored in reservoir **106** is delivered, under pressure, to valves **838**, via fluid-delivery conduits **108**. The liquid that is delivered to valves **838** is dispensed to an underlying receiver, such as micro-titer plate **90**.

Illustrative multi-channel dispenser **100** depicted in FIGS. 1 and 2 is functionally segregated into two portions: a support and positioning portion, and a dispensing portion. The support and positioning portion comprises, in some embodiments of the present invention, support member **102**, horizontally-disposed positioning member **104**, valve-support member **526** and longitudinal positioner **212** (*see* FIG. 2). The dispensing portion comprises reservoir **106**, fluid-delivery conduits **108**, dispensing valves **838** and integrated nozzles **840**.

**The Support and Positioning Portion**

The support and positioning portion of multi-channel dispenser **100** supports the dispensing portion and advantageously facilitates placing the dispensing portion in a position that is suitable for dispensing fluid into a receiver.

The basic configuration for the support and positioning portion has support member **102** receiving positioning member **104** that in turn receives valve-support plate **526**.

With reference to FIGS. 1 and 3, illustrative support member **102** is "u-shaped," having top **314**, and two side members **316** that depend therefrom. The bottom of side members **316** are advantageously configured for interlocking engagement with an underlying structure (not shown). This arrangement provides a reliable alignment mechanism. The facing or opposed surfaces of side members **316** have spaced teeth **318** that define slots **320**.

Support member **102** receives positioning member **104** in slots **320**. In particular, slots **320** receive protrusions **422** that depend from the ends of positioning member **104** (*see* FIGS. 1, 3 and 4).

Multi-channel dispensing head **110** is attached to positioning member **104**. Specifically, valve-support plate **526** (*see* FIG. 5), which is an element of multi-channel dispensing head **110** (*see* FIGS. 1 and 8), is attached to positioning member **104**. Other elements of multi-channel dispensing head **110**, which are described in detail later in this *Specification*, include valves **838** and integrated nozzles **840** (*see*, FIG. 8).

With reference to FIGS. 5 and 6, valve-support plate **526** includes upper receiving portion **528** and lower receiving portion **530** that are connected by side portion **532**. Upper receiving portion **528** and lower receiving portion **530** have holes **736** for receiving valves **838** and nozzles **840** (*see* FIGS. 7, 8 and 1).

Positioning member **104** includes slots **424**, which, in the illustrative embodiment, have an elongate shape. When positioning member **104** engages support member **102**, the long axis of each slot **424** is advantageously horizontally disposed (*see* FIGS. 1 and 3).

Similar to support member **102,** valve-support plate **526** includes two slots **534** (*see* FIGS. 1, 5 and 8) having an elongate shape. In use, slots **424** in positioning member **104** are aligned with slots **534** in valve-support plate **526** (*see* FIG. 1). Valve-support plate **526** is attached to positioning member **104** by passing a bolt or other engagement member (not shown) through slots **424** and **534**. When engaged to positioning member **104**, the long axis of each of slots **534** is advantageously vertically disposed (*see* FIG. 1, *etc.*).

Slots **424** and **534** function, collectively, as a two-axis positioner. In particular, valve-support plate **526** is movable in a transverse direction (*i.e.*, right to left or vice-versa in FIG. 1) along the long axis of slots **424** of positioning member **104**. Moreover, valve-support plate **526** is also movable in a vertical direction (*i.e.*, up and down in FIG. 1).

Vertical movement is provided by moving valve-support plate **526** along the long axis of slots **534** and/or by altering the vertical placement of positioning member **104** in slots **320**. Specifically, protrusions **422** of positioning member **104** can engage slots **320** relatively nearer to the top of side members **316** (*i.e.*, near top **314**) or relatively nearer to the bottom of side members **316**.

In this manner, valve-support plate **526** is suitably positioned in both the transverse and vertical directions to bring nozzles **840** into alignment with a receiver, such as wells **92** of micro-titer plate **90**.

In some embodiments of the present invention, longitudinal positioner **212** (*see* FIG. 2) moves valve-support plate **526** (and positioning member **104**) longitudinally. In FIG. 1, longitudinal movement is "out-of-the-page" or vice-versa and, in FIG. 2, longitudinal movement is "right-to-left" and vice-versa. Longitudinal positioner **212** engages valve-support plate **526** (or positioning member **104**) near one edge thereof (*i.e.*, in FIG. 1, either towards the left edge or the right edge of plate **526**). Consequently, as positioner **212** moves engaged valve-support plate **526**, multi-channel liquid dispensing head **110** is "tilted" in the longitudinal direction. This adjustment allows nozzles **840** to be brought into alignment with wells **92** in micro-titer plate **90** if the micro-titer plate is tilted.

The "tilt" that is imparted to multi-channel liquid dispensing head **110** by longitudinal positioner **212** is depicted, via simplified top view representations, in FIG 9A – 9C. FIGS. 9A – 9C depict micro-titer plate **90** moving beneath multi-channel liquid dispensing head **110** so that the sequential rows of wells can receive liquid from nozzles **840** (not shown in FIGS. 9A – 9C).

In FIG. 9A, micro-titer plate **90** is oriented (properly) such that sequential rows of wells **92** are aligned in parallel with respect to axis **1-1**. Consequentially, as the rows of wells are moved beneath multi-channel liquid dispensing head **110**, nozzles **840** align with each of the underlying wells **92**.

FIG. 9B depicts a situation wherein micro-titer plate **90** is tilted relative to multi-channel liquid dispensing head **110**. That is, rows of wells **92** are not parallel with respect to

axis **1-1**. In this situation, when a row of wells moves into position beneath multi-channel liquid dispensing head **110**, nozzles **840** will not align with all of the wells **92** within that row.

FIG. 9C depicts a situation wherein micro-titer plate **90** is tilted, but, in accordance with the present teachings, liquid dispensing head **110** is tilted in complementary fashion, by the action of longitudinal positioner **212**, such that nozzles **840** align with all underlying wells **92**.

**The Dispensing Portion**

The dispensing portion of multi-channel liquid dispenser **100** includes reservoir **106**, fluid-delivery conduits **108**, valves **838**, nozzles **840** and other ancillary elements.

In use, reservoir **106** is under pressure. This pressure provides the energy required for dispensing liquid. In one embodiment of the present invention, reservoir **106** is pressurized via gas conduit **848** (see FIGS. 2 and 10). A first end of gas conduit **848** terminates at reservoir **106**, and a second end of gas conduit **848** is placed in fluid communication with pressurized gas source (not shown) through operation of a mode selector (not shown), such as a three-way valve and switch. As used herein, the phrase "**fluid communication**," indicates that fluid (*i.e.*, liquid and/or gas) can flow between two regions.

In some embodiments of the present invention, a suction flow is generated through multi-channel liquid dispenser **100** so that a partial vacuum is drawn through reservoir **106** and fluid-delivery conduits **108**. This suction flow allows the dispenser to aspirate (*i.e.*, suck) fluid during a cleaning operation, *etc*.

To generate a suction flow, a second end of gas conduit **848** is placed in fluid communication with a suction flow generator (not shown) through operation of the aforementioned mode selector (not shown). The suction flow generator can be, for example, a pump, jet ejector or the like.

With reference to FIG. 10, reservoir **106** advantageously contains multiple internal chambers or compartments **844**. One advantage of using multiple chambers **844**, in accordance with the present teachings, is that different reagents can be stored in each chamber and subsequently fed to valves **838** for dispensing. Ports **850** are used to fill individual chambers **844**.

A second benefit of using multiple internal chambers **844** is that the impact of a failure in any one channel is reduced. In particular, if one valve **838** or liquid channel leaks or

otherwise fails, the loss of reagent is limited to the reagent in the associated chamber **844**. And this applies to any mode of valve failure or other malfunctions. By contrast, in the case wherein multiple valves are fed by a common reservoir, if one valve were to fail in the open position, all of the reagent in the reservoir would be lost.

In the illustrative embodiment, reservoir **106** has eight chambers to supply eight dispensing channels. Of course, in other embodiments, reservoir **106** is suitably provided with more or fewer internal chambers as is appropriate for the number of dispensing channels in dispenser **100**.

Region **846** above chambers **844** is not compartmentalized. Non-compartmentalized region **846** facilitates an even distribution of pressure within reservoir **106**, thereby promoting the balanced dispensing of liquids through multiple valves **838**. Furthermore, non-compartmentalized region **846** allows for ease in filling reservoir **106** in embodiments in which a single reagent is used in all chambers **844**.

Fluid-delivery conduits **108** place valves **838** in fluid communication with reservoir **106**. Fluid-delivery conduits **108** are advantageously very short to reduce the impact of temperature/viscosity fluctuations, internal gas bubbles, elasticity variations of the tubing, and the like. Moreover, short conduits also keep reagent losses to a practical minimum during priming, cleaning, purging and servicing operations. Fluid-delivery conduits having a length in the range of about 5 – 10 millimeters have been found to be acceptable for such purposes. It will be understood that fluid-delivery conduits longer than 5 – 10 millimeters can be used, but the potential impact of the above-described variations will increase concomitantly. Fluid-delivery conduits **108** are suitably formed from tubing, such as TYGON™ tubing, which is commercially available from Norton Performance Plastics, Akron, Ohio.

Valves **838** control the dispensing operation. The amount of liquid dispensed is advantageously controlled to a specific volume, which is primarily a function of (1) the amount of time that valves **838** are open and (2) the pressure level in fluid-delivery conduits **108** or reservoir **106**. To a lesser extent, the dispensed amount of liquid also depends on liquid properties (*e.g.*, viscosity, *etc.*).

Valves **838** are advantageously "micro" valves, such as are used for print heads in ink-jet printers. Micro-valves are capable of dispensing micro-volumes of fluid in the range of about 20 nano-liters to several micro-liters. Micro-valves are commercially available from The Lee Company of Essex, Connecticut, and others.

Nozzles **840** are in fluid communication with valves **838** and ultimately dispense the liquid stored in reservoir **106** into a receiver, such as wells **92** of micro-titer plate **90**. In some embodiments of the present invention, nozzle **840** is an integral portion of valve **838** (*i.e.*, it is obtained from a supplier as a combined valve/nozzle), while in other embodiments, separate valves and nozzles are suitably used.

In some embodiments of the present invention, micro-titer plate **90** is advanced toward multi-channel liquid dispensing head **110** via incremental positioner **952**, which is represented by drive **954** and stage **956** (*see* FIG. 11). Micro-titer plate **90** rests on stage **956** and drive **954** advances stage **956** towards multi-channel liquid dispensing head **110**.

One incremental positioner suitable for use in this service is the positioner disclosed applicant's co-pending patent application entitled "Article Comprising an Incremental Positioner," which was filed on September 14, 1999 as serial no. 09/395,132 and is incorporated herein by reference. That positioner is reliable, fast and inexpensive, and is therefore advantageously used. Other more complicated arrangements for incremental positioning, such as a stepper motor used in conjunction with a processor, as is known in the art, may suitably be used, as well.

**<u>Flow Control Features</u>**

One or more of the following optional flow-control features are advantagously incorporated into liquid dispenser **100** to improve the accuracy of the fluid dispensing operation.

If liquid is dispensed squarely into (*i.e.*, orthogonal to the bottom of) well **92** of micro-titer **90**, it can splash off of the bottom of the well. In fact, a portion of the dispensed liquid is likely to splash out of the well. The result of this is, of course, that the desired amount of liquid is not retained by the well and, furthermore, other wells might be contaminated with the splashed liquid.

Moreover, when liquid is squarely dispensed into well **92**, an air bubble(s) is often trapped. The bubble may burst after some time, thereby causing liquid to splash out of well **92**. Alternatively, the bubble might not burst, and the presence of the bubble can interfere with analyses.

This problem is addressed, in accordance with the present invention, by varying the angle at which liquid is dispensed into a well, as described below.

In some embodiments of the present invention, fasteners, such as nuts **842**, attach valves **838** and integrated nozzles **840** to valve-support plate **526**. Nozzles **840** are received by holes **736** in upper receiving portion **528** and lower receiving portion **530** of valve-support plate **526** (*see*, *e.g.*, FIG. 8). The diameter of holes **736** that receive nozzles **840** is substantially larger than the outside diameter of the nozzles.

Referring now to FIG. 12, each fastener (*e.g.*, nut **842**) receives a valve **838** and integrated nozzle **840** in eccentrically disposed hole **1058**. In one embodiment, eccentrically disposed hole **1058** is provided by placing bushing **1060** (having an eccentrically disposed hole) within the centrally located hole **1062** of a standard nut. As nut **842** is rotated, engaged valve **838** and nozzle **840** "tilt" relative to the vertical. Such tilting is facilitated by oversized holes **736**. This tilting is depicted, figuratively, in FIG. 13 wherein nozzle **840** is not aligned with vertical axis **2-2**.

The ability to tilt valves **838** and integrated nozzles **840** in this manner allows liquid to be dispensed along an off-normal path towards the bottom of wells **92**. Consequently, a dispensed liquid droplet(s) ricochets off the bottom of well **92** and towards a side-wall thereof. The droplet ricochets off the side wall, now moving in the direction opposite to which it entered the well. When delivered in this manner, there is a substantially reduced tendency to trap air. Moreover, the reflections dissipate the energy of the droplet such that liquid tends to remain in the well.

The following optional features are disposed in/on fluid-delivery conduits **108**. In embodiments in which such optional features are included in dispenser **100**, fluid-delivery conduits **108** are suitably lengthened to accommodate such elements. The previously described drawbacks that result from increasing the length of fluid-delivery conduits **108** are tempered by these optional flow control features.

Illustrative dispenser **100** has eight channels for dispensing liquid. It will be appreciated that differences might arise in the operating behavior of the various channels, especially over the course of a usage cycle. Such differences might be due, for example, to variations in valve performance from channel to channel, or to channel-to-channel variation in the degree to which fluid delivery conduits, valves and/or nozzles are occluded.

To this end, adjustable orifices or pinch valves **1164** are advantageously provided in fluid delivery conduits **108** near where they join valves **838** (*see* FIG. 12). Adjustable orifices **1164** are operable to affect dispensing speed and therefore able to synchronize the

dispensing operation of all channels of dispenser **100** to compensate for any channel-to-channel variations that might occur.

The following flow-control features are described in further detail in applicant's co-pending U.S. patent application entitled "Article and Method for Flow Control in Fluid Dispensing Devices," which was filed on September 14, 1999 as serial no. 09/395,383. This application is incorporated herein by reference.

Dispensers that provide a constant "re-supply" of fluid to replace dispensed fluid, such as illustrative dispenser **100** depicted in FIG. 1, are susceptible to a characteristic error. The error is related to certain performance attributes of the valve. In particular, the amount of fluid that is dispensed from such dispensers is proportional to the amount of time that the valve is open. The valves (*e.g.*, valves **838**) that are typically used in such dispensers exhibit a rapid response to an impulse (*e.g.*, voltage) to open, but the closure response tends to be less precise, as a function of the spring used in the valve.

With reference to FIG. 14, in some embodiments of the present invention, a flow restriction, such as restriction orifice **1166**, is disposed in fluid conduit **108**. The flow restriction is advantageously disposed at the input (*i.e.*, at the interface between reservoir **106** and the fluid conduit **108**) of fluid conduit **108**. In some embodiments, fluid conduit **108** is elastic, or has a region that is elastic, such that it functions as an accumulator or bladder. Restriction orifice **1166** has an outlet orifice **1168** that is smaller than the opening of dispensing valves **838**. As a result, fluid is re-supplied to fluid conduit **108** more slowly than it is dispensed through valve **838**. Errors resulting from any delay in valve closure are therefore reduced in magnitude since the flow rate to valve **838** is reduced by limiting the re-supply rate.

It is advantageous to monitor the pressure in fluid conduit **108** as it falls and rises during respective dispensing and refilling cycles. Such pressure data can be correlated to an amount of fluid dispensed and also provide indications of operational problems (*e.g.*, occlusions in the fluid conduit **108**).

Consequently, in some embodiments of the present invention, pressure sensing is provided. Dynamic pressure sensors (*e.g.*, piezo resistive sensors, *etc.*) are advantageously used for such pressure sensing since they are much less expensive (*i.e.*, about an order of magnitude) than static pressure sensors and typically provide sufficient information. At least a portion of fluid conduit **108** must be elastic to use a dynamic pressure sensor.

In an embodiment depicted in FIG. 14, dynamic pressure sensor **1170** is operatively engaged to an elastic region of fluid conduit **108**. Leads **1172** from sensor **1170** connect to appropriate electronics (not shown) for processing sensor data and displaying and/or recording such data. In some embodiments, the present dispenser includes both a restriction orifice **1166** and dynamic pressure sensor **1170** to improve accuracy.

Over time, the performance characteristics of a fluid dispenser may change. For example, elastic conduit may lose resilience over time. Moreover, variations in fluid parameters (*e.g.*, changes in viscosity, *etc.*) from use-to-use may affect the fluid dynamics within the dispenser and hence the dispensing operation itself. To the extent that such a change in elasticity or in fluid parameters varies from a baseline condition, there will be a difference between the actual amount and the desired amount of liquid dispensed.

In one embodiment, pinch valve **1164** described above is operable to compensate for such changes. In a second embodiment in accordance with the present teachings, a resilience-adjusting element is operable to adjust the "resilience" or "elasticity" of an elastic region of fluid conduit **108**. By appropriately adjusting the resilience-adjusting element, dispenser operation can be maintained at a baseline notwithstanding changed system conditions. Such adjustment is best performed via trial and error, wherein the resilience-adjusting element is changed and the dispensed volume measured. The resilience-adjusting element is adjusted until the proper volume is dispensed. Of course, a user can adjust valve operation and/or pressure to affect changes in the dispensed volume, as well.

In the embodiment depicted in FIG. 14, the resilience-adjusting element comprises an enclosure **1174** that defines a pressure-tight chamber surrounding at least a portion **1176** of an elastic region of fluid conduit **108**, and a pressure-adjustment element. Increasing the pressure within chamber effectively increases the resilience of the enclosed region of fluid conduit **104**.

In some embodiments, the pressure-adjustment element is realized by gas supply conduit **1178** that delivers gas (*e.g.*, nitrogen, *etc.*) to enclosure **1174**, and pressure regulator **1180**. Additionally, an optional vacuum-flow conduit (not shown) for drawing a partial vacuum can be connected to enclosure **1174**.

In a further embodiment, dispenser **100** incorporates a flow monitor/controller for monitoring and controlling liquid flow, as described in detail in applicant's co-pending U.S. patent application entitled "Article and Method for Predictable Dispensing of Small Liquid

Volumes," which was filed on January 31, 2000 as serial no. 09/494,387. This application is incorporated herein by reference.

As used in this *Specification*, the phrase "**flow control features**" refers to any of the features described in this section (*i.e.*, eccentrically-disposed hole in fastener, pinch valves, restriction orifice, dynamic pressure sensing, resistance-adjusting element and flow monitor/controller) that are operable to control liquid flow.